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Digital Twin: An Enabler for New Business Models

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Abstract

Derzeit bieten immer mehr Firmen die Idee eines Digitalen Zwillings als Teil ihres Portfolios digitaler Lösungen an. Die meisten aktuellen Angebote für IoT Systeme sind dabei auf Cloud-basierte Informations- und/oder Simulationsmodelle beschränkt. Trotzdem gibt es bisher keinen Konsens darüber, was genau Digitale Zwillinge überhaupt ausmachen. Beispielsweise ist oft unklar, wie sie zur Wertschöpfung und zu digitalen Geschäftsmodellen beitragen, welche Technologien nötig sind, um Digitale Zwillinge zu erzeugen, wie Digitale Zwillinge miteinander interagieren, ob Digitale Zwillinge direkt an eine IoT Lösungen gebunden sind oder ob sie sogar schon bereits existieren und bisher lediglich einen anderen Namen hatten, usw. Dieser Artikel analysiert diese Fragenstellungen aus Sicht der Industrieforschung.

Abstract (optional)

Companies now offer the notion of *digital twin* as part of their digital solution portfolio. Most current proposals are limited to IoT systems with information models managed from the cloud and/or simulation models. However, we have observed that there is no consensus on the definition of the digital twin. For example, how digital twins can contribute to the value propositions and digital business models of a company; what technologies are required to build digital twins; how digital twins can interoperate; whether digital twins are exclusively bound to IoT solutions or if they even existed before, simply under a different name; etc. This paper studies these topics from an industrial R&D perspective.

1. Introduction

Industrial companies have been using digital representations for many years to model the information of an asset (e.g., a device, a production cell, a plant) across its lifecycle, however not always branded as a *digital twin*. Today, additional values for digital twins beyond information models are mostly related to improvements in digital technologies, development and standardization of architecture, interactions, new use cases and the business models that digital twins enable. We classify these as depicted in Figure 1 below.

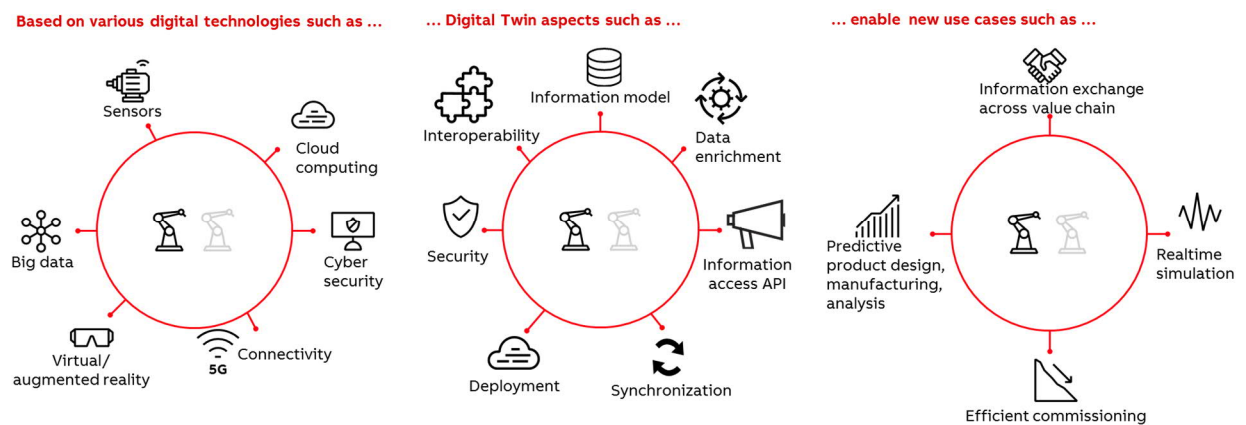


Figure 1: An overview of related topics to Digital Twin

The notion of digital twin is about collecting, maintaining, aggregating, processing, and providing information about assets. This includes dedicated sensing mechanisms, and often needs Big Data capabilities if the amount of available data is excessive. For most digital twin use cases, it is necessary to store information externally, for example in the cloud, yet require reliable and low latency connectivity to the industrial operators, assets and processes. Suitable security mechanisms are paramount to control and manage access to the information for collection and exchange.

Where most companies offer their digital twins as an isolated solution, many use cases benefit from interactions between multiple digital twins provided by different companies. This highlights the need for interoperability aspects of digital twins, and the related data exchange, synchronization and administration aspects.

Digital twins can enable new use cases with these technologies and interactions in place. Examples scenarios are: Information exchange across the value chain, real-time simulation of production systems, efficient commissioning of devices and plants, and predictive product design, manufacturing and analytics. This paper provides a consolidated view on digital twins and discusses their enabling roles for new business models.

2. Digital Twin: Evolution of the Term

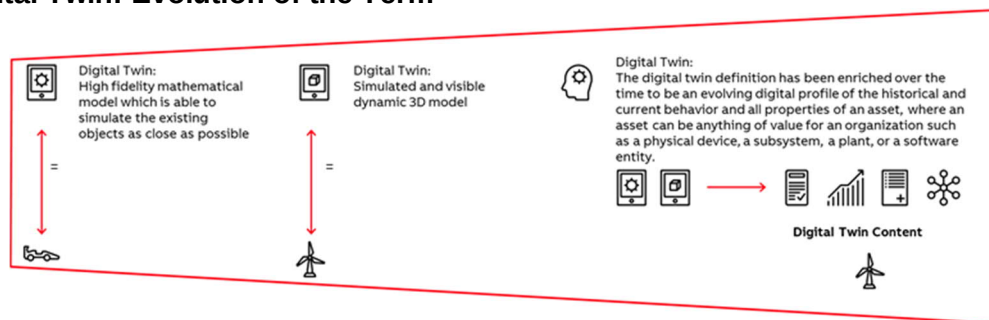


Figure 2: The evolution of the Digital Twin term [11]

As depicted in Figure 2 above on the left side, digital twins were initially considered to be high fidelity mathematical models to reflect the behavior of real assets as close as possible [3]; this perception has evolved to include simulated and visible dynamic 3D models of real-world assets. The digital twin definition has been enriched over the time to be an evolving digital profile of the historical and current behavior and all properties of an asset, where an asset can be anything of value for an organization such as a physical device, a subsystem, a plant, or a software entity. Figure 3 shows some example content, which could be assigned to the digital twin, depending on the use case.

	Product Design	Production Planning	Build	Operate	Maintain
Product lifecycle information	PLM	PLM	PLM	Operation instructions	Service records
3D representation	Design drawings	Design drawings	Manufacturing instructions	Plant visualization	Service instructions, AR
Model	Behavior prediction	Behavior prediction	Virtual commissioning	Control performance	Diagnostics
Simulation	Design simulation	Design simulation	HW-in-the-loop tests	What-if studies	Prediction
Data model	Engineering data	Engineering data	Manufacturing data	Operational data	Service data
Model synchronization				Real-time movement	Model inversion
Connected analytics	Manufacturing Operations Management KPI	Manufacturing Operations Management KPI		Operational KPIs	Asset health KPIs
Visualization	Design tool	Design tool	Design tool	Operational state display	Health status display

Figure 3: Example content of a digital twin

3. Technical Aspects of Digital Twins

There are many potential use cases of digital twins, as shown in Figure 3 above. Not every content needs to be provided for each solution, but all digital twins must manage data and communicate with applications, and potentially interoperate with other digital twins. Table 1

outlines technical aspects that need to be considered while designing digital twins and gives some examples of their capabilities. More details are provided in [12].

Table 1. Digital Twin Features

Aspect	Capability	Motivation
Information Model	Integrated information model	Asset types and instances are crucial aspects of the ecosystem, which must be discoverable, navigable and organized independent of naming conventions. The (semantic) link/relations among information must be maintained within digital twins.
	Flexible classification of types, properties and instances	Every digital twin can bring its own type definition, imposing the constraint on clients to configure and program accordingly. It is unrealistic that all applications will agree on a common taxonomy and attributes.
Data Enrichment	Data ingest configuration for each column store	Digital twins are populated by creating key-value pairs and data source ingest is a ubiquitous architectural scenario.
	CRUD (Create/Read/Update/Delete) data exchange with cascading side effects based on role	Writing and reading key-value pairs in the digital twin column stores is the fundamental application programming model for persistence and analysis.
Information Access API	Publish and subscribe notification of CRUD transactions	Digital twins enable clusters of processing activity in an architectural tier by generating events associated with information access.
	Request-based information access	Digital twins may offer APIs to other services to access and manipulate its content.
Synchronization	Filtered synchronization between architectural tiers	Communications between digital twins may not be reliable or is intentionally air-gapped for security protection.
Deployment	Flexible deployment of digital twins	The digital twin information model and policy definitions are deployed as first-class participants in the ecosystem independent of services that use the digital twin.
Security	Encrypted data at rest and in transfer	Encryption is used both for data exchange and synchronization transactions to prevent unauthorized access.
	Role-based access control configured for authenticated users	A digital twin imposes a security domain to protect and manage access to data. Synchronized digital twin replicas in adjacent architectural tiers are guarded by the same controls.
Interoperability	Diverse information format within a digital twin	Different kinds of information within a digital twin may be represented in different industry standards.
	On demand translation of information formats	Information within a digital twin may be translated on demand to a certain format that is understandable by other vendors.

4. Digital Twin Adoption in Industries

Some of the technology we now call digital twin has been used by industry for decades. This includes process supervisory and control systems, data bases and historians. Many industrial applications that were built as digital twin precursors are still in use today. Other use cases are fueled by the Industrial Internet of Things (IIoT). The following chapter shows some examples of various potential use cases before and in the IIoT era.

4.1. Digital Twin to Enable Integrated Automation, Information, and Collaborative Business Processes

Problem: A central problem in plant operations as well as asset lifecycle management is that we need a way to keep together, manage, and have access to information about all different aspects of a great number of plant and process entities. In a system that integrates automation, information, and collaborative business processes across the enterprise, each of these real-world objects needs to be described from several different perspectives. Each perspective defines a piece of information, and a set of functions to create, access, and manipulate this information. Therefore, suitable technologies are needed to define all these in a modular way, so that new information can flexibly be added upon its availability.

Digital Twin Solution: At Xerox PARC in 1990's there were ideas for aspect-oriented programming (AOP) [1], which clearly expresses programs with cross-cutting aspects for isolation, composition and re-use. Shortly after the inception of AOP, architects at ABB [2] extended those concepts to develop a knowledge representation for industrial controls, as shown in Figure 4. This is named as Aspect Object, which is standardized in IEC-81346, and is now further extended to have an OPC Unified Architecture (OPC UA) [6] representation.

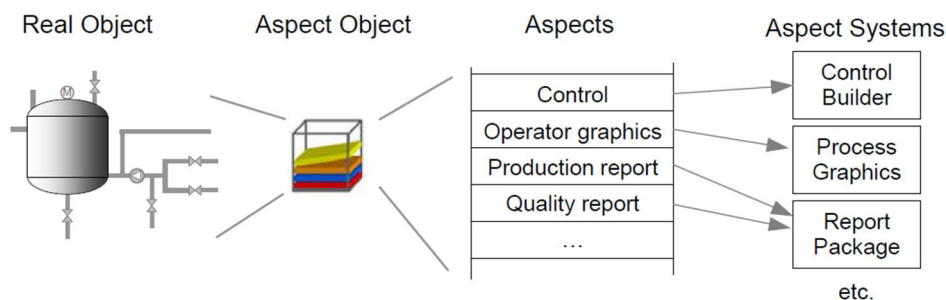


Figure 4. Defined aspects are implemented by different aspect systems.

The focus of Aspect Object is to ensure the widest interoperability across equipment vendors and to define type systems and metadata that characterize industrial assets and facilitate data exchange. The vision is to enable this ecosystem vertically, from the most primitive devices up to business processing systems. In addition, the representations could be used for the entire product life cycle: from design and implementation to commissioning and operation.

Value Proposition: The Aspect Object technology can be seen as a digital twin solution, which enables advanced applications such as remaining lifetime estimation or advanced process control [5]. It organizes data, metadata and functions in a digital tree structure that can be navigated interactively and programmatically using a fourth-generation programming language. In 2002, ABB reported hundreds of products integrated using this single architecture

[3]. One example is ABB's BoilerMax [4] application. This non-linear model-based predictive control speeds up unit start while obeying the thick-walled components' thermal stress limits and minimizing fuel consumption. Speeding up steam boiler startup without damaging the equipment is just one of many applications that had been developed based on the Aspect system during the years.

4.2. Digital Twin to Enable Virtual Commissioning of Production Systems

Problem: Key challenges facing industrial automation projects are identifying, ordering and taking delivery of the necessary systems, preparing the facilities and installing the equipment, and configuring and testing the operations. Delays in shipments, missing or broken parts, misaligned integrations, and availability of staff and contractors can significantly impact the timeline and milestones where revenue can be generated.

Digital Twin Solution: Virtual commissioning, in which simulation models are digital twins, addresses many of these concerns by enabling process and supervision verification ahead of any purchase or logistic challenges. In a hybrid simulation both spatial and data characteristics needed to be considered to trigger procedural and Newtonian effects [7].

For example, Chalmers University did a case study [8] for a robot cell modeling the machines, centrifuges, robot, PLCs and I/O. Time and resources can be saved by using virtual commissioning. The visualization is shown in Figure 5.

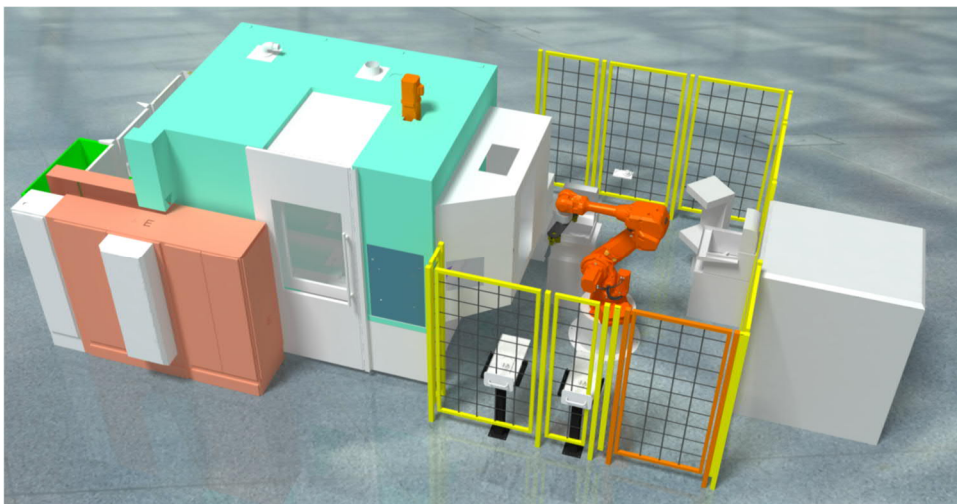


Figure 5. Case study of an existing robot cell at Scania

Value Proposition: Integrating digital twins into automation processes helps to decrease the required time and effort to commission machines on the plant floor, and to accelerate time to production. The serial process of machine building (e.g., from 3D mechanical concept design to electrical engineering, automation and programmable logic controller (PLC) configuration)

can become a parallel process by enabling automation and design engineers to work in parallel. There is still room for innovation and much work needs to be done. Researchers have surveyed [9] how cyber-physical integration can be implemented in digital factories, including models for commissioning and operations.

4.3. Digital Twin to Enable Information Exchange across the Value Chain

Problem: Industrial automation systems usually suffer from the *information silos* problem: The data and calculated values related to different lifecycle phases of an asset (e.g., Figure 3) is scattered across multiple sources. These repositories are often maintained by different internal/external organizations and are interfaced by different applications. This leads to missed opportunities across the lifecycle of assets because the sources do not properly exchange information; some records may be duplicated or inconsistent and some information may be missing. As a result, there are delays to find the relevant data, to convert to a suitable format, and to pass the information to different tools, etc.

Digital Twin Solution: The digital twin of an asset can be seen as a unifying interface to access the lifecycle data of the asset and providing continuous information flow across its lifecycle [11]. The records may be aggregated from various sources into the digital twin of the asset, may be represented in different formats (e.g., AutomationML for engineering data and OPC UA for operational data), and links established among the correlated information to maintain the flow of information across the lifecycle. Information flow may go beyond the boundaries of a company, which means the recommendations and decisions must be presented in a standardized format to ensure interoperability across companies. Asset Administration Shell proposed by Platform Industrie 4.0 in Germany can be adopted here.

Value Proposition: The digital twin of an asset helps to reduce the required time and effort to access information, to maintain links among the records and to increase the application quality by avoiding redundant and isolated information. This is the enabler for new use cases such as *Realtime Simulation*, *Efficient Commissioning of Field Devices*, and *Produce and Predictive Product Design, Manufacturing and Analytics*.

4.4. Digital Twin to Enable Realtime Simulation

Problem: Traditionally, simulation and operation of a plant, a system or a device were treated as two different things. Simulation software is mainly used during the development phase, where engineers build high-fidelity models using simulation software tools to get a better understanding *before* the physical device is built. These models are usually Finite-Element Models (FEM) to simulate the physical behavior or non-linear, high-dimensional, time-variant models to simulate the dynamical behavior.

After the device is built and installed at the customer site, new models are built for condition monitoring and reliability engineering. These models are typically less complex since they must run in real time within the storage and computational capacities of the hardware available on-site. To be able to create these models, high quality and well documented data has to be gathered from various sources. As a result, many models are generated during the life time of the asset, but the models are rarely reused.

Digital Twin Solution: By integrating various models in the digital twin of an asset and establishing relations among the models, the digital twin allows existing models to be used for different purposes. For example, FEM can be used (after model-size reduction) to continually monitor the stress in a physical structure; not only detecting the issue but also helping with root cause identification and isolation. Therefore, the model must be exposed as a data source in the digital twin by the simulation expert who created it. This process includes a proper description of the model, its inputs and outputs and everything else needed to run the simulation model. For example, the reliability engineer can later reuse the model and connect it to the physical system. This simplified model is fed with continuous data and the concurrent simulation provides continuous predictions for the real-world states.

Value Proposition: An existing model can be reused for different purposes (e.g. FEM can be reused for online Condition Monitoring), to increase the quality and functionality of applications using accurate models, and the time to market reduces because the models are already available and do not need to be created twice.

4.5. Digital Twin to Enable Efficient Commissioning of Field Devices

Problem: Today, deriving the correct configuration for field devices from an existing process design requires manual work. Information from engineering or earlier lifecycle phases of field devices exist in different sources in different formats, which are not necessarily standardized. Therefore, time and effort is consumed to access the data, find the right information, interpret the records and finally commission field devices and provide optimal configurations for them. This effort is repeated when devices are broken and need be replaced.

Digital Twin Solution: The digital twin of a field device enables the plug and produce scenario for field devices to reduce the required time and effort for the commissioning of the field devices. Various advanced technologies, for example automatic device discovery and cloud computing in combination with adopting standardized information formats such as AutomationML and OPC UA, can be used to automatically discover devices connected to the network, map engineering and operational parameters to each other, and download the parameters from the cloud to the devices. While the physical replacement still requires trained

personnel, the digital twin allows instant re-configuration without need for a device or process expert.

Value Proposition: In combination with other technologies, the digital twin of a field device helps to significantly reduce the time for the basic engineering and commissioning of field devices. This becomes feasible by maintaining the information flow across lifecycle phases of the field devices.

4.6. Digital Twin to Enable Predictive Product Design, Manufacturing and Analytics

Problem: Production design, manufacturing and analytics are three distinct topics which usually involve different stakeholders: A) Production engineers ideate and develop a new production setup when a new production facility should be set up or an old one redesigned. For this purpose, the engineers use design and simulation tools to get a better idea about the setup. B) Then, the new production facility is erected by civil engineers, and manufacturing of the new plant starts. In this phase, engineering plans are created by automation engineers identifying assets, measurement devices, and related identification numbers. C) Finally, performance improvement engineers establish condition monitoring systems or KPI calculation engines to measure and improve the performance of the production facility. Usually, these three steps are executed in a sequence, which may lead to undesired cases such as setting up the production facility by having wrong performance measures in mind.

Digital Twin Solution: The digital twin of a production system is a means to make all data and models available across lifecycle phases to different stakeholders. For example, the moment the initial setup is available, engineers could provide an initial P&ID diagram and performance engineers could start planning for condition monitoring and performance analytics. If they in return make these models available via the digital twin, production engineers could use them already during the planning phase. In condition monitoring analytics, for example, the exact performance measurements could be calculated to obtain clues about which setup will maximize the KPIs.

Value Proposition: The digital twin of a production system helps increase parallelism in production design, manufacturing and analytics development. In addition, it helps optimize production design by taking the real-world performance and condition monitoring analytics into account.

5. New Business Models fueled by Digital Twins

Several business models like guaranteed availability, pay-for-performance or pay-per-use had been discussed throughout the years. However, not many of these approaches have survived, hardly any of those were commercially successful. Most ideas ended up as a form of a leasing

contract, where the only difference from a traditional product sale is the question of who's balance sheet the asset is on. One of the main reasons for the unsatisfactory results was the lack of continuous and reliable access to the device and its properties and data. This might change with the wide-spread use of digital twins.

Many features provided by a digital twin do not have an immediate impact on the business model around a physical object. Already today it is possible to simulate equipment, deliver the 3D models or other documentation along with the object, or analyze data that the equipment is providing. However, as the previous use cases have already laid out, the digital twin makes this easier, more accessible and less error prone, leading to more efficient and individual services.

5.1. More Efficient with Less Errors

Having a broadly agreed means to access and exchange data that is related to a physical object eases collaborative engineering throughout all the lifecycle stages. This reduces the time spent on finding, exporting, and importing data into the tools required for any lifecycle task. Faster access to information shortens project runtime in greenfield projects. Even more value is provided if digital twins help resolve operational or maintenance issues that result in expensive downtime of the plant.

Another key value delivered by digital twins is an increase in quality. Many errors in production are caused by relying on wrong or outdated data. If detected, inconsistent and incomplete documentation requires time-consuming extra work, causing major delays. Or, if not detected, may even cause production quality issues or production losses. Always having access to the current information related to an object avoids this.

5.2. Always Accessible

Another paradigm shift coming along with digital twins is their accessibility. In contrast to the physical device, a digital twin and all its aspects can be made available to anyone involved in the life cycle of the product. Sharing the digital twin - for instance in the cloud - allows experts to access relevant data anytime and anywhere. Granted respective user roles and rights, several experts can work and collaborate on the same asset, leveraging their diverse expertise in the best possible way. In addition, trouble-shooting and optimization can be done independent from and non-invasive to the physical device, before implementation. Sharing expertise around the world allows for 24/7 service and fast reaction time while maximizing expert utilization. In case an implementation needs on-site operation, a local engineer can be mobilized, and remote experts can provide support. Service steps can be tested first at the virtual twin before guiding a local engineer. This virtual on-site support can be executed

through virtual and augmented reality devices, utilizing the 3D model and real-time data of the twin.

5.3. X-as-a-Service in Cloud

The emergence of cloud-based solutions enabled so called X-as-a-service business models. These service models can be subdivided into: Infrastructure as a Service (IaaS), Platform as a Service (PaaS) and Software as a Service (SaaS) [10]. In the IaaS model IT infrastructure is no longer purchased, but it can be accessed dynamically through a service contract. With PaaS models, whole development environments are provided, allowing customers to develop and share their own software applications and algorithms. In the SaaS model software vendors have started offering software packages, where the software is not owned, but subscribed to. Some attempts have been made to offer other products 'as a service'.

The notion of digital twin brings a new aspect to the question of the 'as-a-service' business model. While many industrial devices today contain software in some form or another, digital twins allow the allocation of functionality that is detached from assets. An asset that is purchased from a vendor in a traditional business relationship can have extended functionality that resides in the digital twin ecosystem around an IoT platform. The digital twin can then provide all the functionalities earlier described in the use cases in varying business models. Some of the functionality, e.g. predictive maintenance, can be provided as part of a recurring service contract. What-if studies or on-demand performance analysis or simulations can be sold as a one-time service. Other services, such as virtual commissioning, are provided as part of the asset purchase and do not require a separate service contract.

An interoperable digital twin concept opens a whole range of new service opportunities to suppliers related to a set of assets. The data provided by the digital twin can be subscribed to, or made available off-line for a one-time fee. Business models that have been established in cloud computing can now be related to physical assets. New services can be added as required, but when digital twin-based services are cancelled, the owner of the asset still has a fully functional, though not continuously optimized, device.

6. Conclusion

Whatever business model we apply, in the long run it will only be successful if it creates a win-win situation along the value chain, or at least does not add an additional burden. Even though, the benefits can be subtle at the beginning, they will sum up in the long run. Just a few minutes less in finding the right manual or service record can result in days of effort saved. Getting more detailed information about the installed base and its behavior in the field, may lead suppliers to an improved product design or more advanced predictive maintenance models.

Both providing a competitive edge in the future. In order not to jeopardize these saving, applying digital twins must be as easy and straightforward as possible. Thus, harmonizing data exchange and reducing overhead of engineering as described in the previous chapters is not only a technical issue, but a question of survival. If zero marginal cost is the goal, this is the way to go.

Acknowledgement

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